

A succession and silviculture model for the broad-leaved Korean pine forests of Changbai Mountain Area¹

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Abstract A succession and silviculture model (ZELIG.CBA) for broad-leaved Korean pine forest of Changbai Mountain Area was developed based on the framework of ZELIG model and characteristics of Broad-leaved Korean pine forests of Changbai area. ZELIG.CBA model consists four sub-models: growth model simulating annual increment of individual tree in forest, regeneration model simulating annual establishment of different tree species, mortality model simulating annual age-related and stress-related mortality; and silviculture model simulating the forest response to different silviculture scenario. The validation of the ZELIG.CBA showed that the accuracy of the model for the forest growth was more than 95%. The succession from clear cutting site simulating showed that the ZELIG.CBA model was stable for long term simulation. And selective cutting experiment showed that the optimal scenario for broad-leaved Korean pine forests was removal volume 30% combining with 30a rotation.

Key words: Gap model, Broad-leaved Korean pine forests, Simulation

Introduction

Gaps in forests were often formed due to big trees fall down. Regeneration and growth in the gaps increase because of the improvement of light condition. The gap will be filled with new regenerated trees. Watt named this forest dynamics as the forest growth cycle. Since D. Botkin developed the first Gap model (JABOWA model) based on the forest growth cycle theory, the research on gap model became one of the most active directions in ecology because of JABOWA model's success. H. Shugart and his students made great contributions to gap model's development. Most Gap models came from FORET model (H. Shugart and West 1977).

The Gap model of broad-leaved Korean pine forests in Changbai Mountains developed in the past focuses on the growth, succession and response to global climate change. Since the sustainable management of broad-leaved Korean pine forests is a very important issue for log production, the purpose of this study is to develop a model for simulating the dynamics of broad-leaved Korean pine forests and its response to different management scenario.

Study area

The broad-leaved Korean pine forests distribute mainly in Changbai Mountain and Xiaoning'an Mountains. Changbai mountain range stretches along the boundary between

China and North Korea. The study area extends from 127°06' to 128°16' E and 41°21' to 42°25' N. Elevations range from about 500 to 1100 m above the sea level. This the region is affected by monsoon climate and features a temperate continental mountainous climate, cold in long winter and short cool in summer. The annual mean temperature ranges from 2°C to 4°C. Average annual precipitation is 630-780 mm and mainly distributed in July and August. The accumulated temperature of $\geq 10^{\circ}\text{C}$ is about 1500 $^{\circ}\text{C}$ days, and frost-free period is 100-120 days.

Soil type is the mountainous dark brown forest soil. The typical broad-leaved Korean pine forest, which consists of abundant species and complex structure, is multi-storied and uneven-aged. The dominant tree species are *Pinus koraiensis*, *Tilia amurensis*, *Fraxinus mandshurica*, *Quercus mongolica*, *Ulmus Japonica* and *Acer mono*. The coverage of shrub layer is 0.4 and herb layer 0.8.

ZELIG.CBA model

Model structure

ZELIG.CBA model, a computer model for simulating the dynamics and silviculture of broad-leaved Korean pine forests in Mt. Changbai, is an individual-based "Gap model" which was derived from the ZELIG model of Smith and Urban (1991) and ultimately from the FORET model (Shugart and West, 1977) and JABOWA model of Botkin *et al* (1972a,b). ZELIG.CBA consists of four pri-

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mary subroutines: regeneration, growth, mortality and silviculture. ZELIG.CBA modified regeneration sub-model of ZELIG adapted to characteristics of the broad-leaved Korean pine forest; added algorithms of underground water affecting regeneration and growth of forest.

Like its parent and sibling models, ZELIG.CBA simulates forest dynamics by accounting the establishment, annual diameter growth, and mortality of each individual tree in the simulated forest. The basic approach in modeling each of these demographic processes is to begin with a maximum potential behavior and subsequently modify this potential accounting to the status of the individual tree in the context the resources available on the modeled plot.

Diameter growth function

the optimal DBH increment function is the same as ZELIG

$$\left(\frac{dD}{dt}\right)_{opt} = \frac{G(1 - DH/D_{max}H_{max})}{DH_{max}[-Db_1b_3\exp(b_2D)][1 - \exp(b_2D)]^{b_3-1} + 2[1 - \exp(b_2D)]^{b_3}} \quad (1)$$

Where b_1, b_2, b_3 are parameters of Richards function; G is tree growth parameter. Table 1 includes main specific species parameters used in ZELIG.CBA.

The actual increment of DBH is as

$$\frac{dD}{dt} = \left(\frac{dD}{dt}\right)_{opt} * f_t * f_l * \min(f_{sf}, f_{sd}, f_{sw}) \quad (2)$$

Where f 's parameters are separately modify factor of tree growth environment such as light, temperature, soil moisture and soil fertility.

Available light function

species response to available light was described by the function as:

$$f_l(S_h) = c_1(1 - e)^{c_2(S_h - c_3)} \quad (3)$$

Where, c_1 is a scaling constant, c_2 determines the rate of change in growth relative to change in sunlight, and c_3 is the light compensation point (where net growth is 0). S_h is the light available at height h , the light extinction through a forest canopy as a negative-exponential decay following the Beer-Lambert Law, as demonstrated by Monsi and Sacki(1953):

$$S_h = S_0 \exp[-k * LAI(h)] \quad (4)$$

Where S_0 is incident light, and $LAI(h)$ is cumulative leaf area index (m^2/m^2) above height h . Here k is a constant describing light extinction through the canopy; generally, k takes on values in the order of 0.30-0.50 (Monteith 1973), and in ZELIG.CBA is set to 0.40.

Table 1. The species-specific parameters in ZELIG.CBA

species	A_{max} /a	D_{max} /cm	G	H_{max} /m	b_2	b_3	DD_{min} (day°C)	DD_{max} (day°C)	L	D	M	F
<i>Pinus koraiensis</i>	400	160	507	31.84	-0.304	1.034	600	2850	2	4	2	3
<i>Larix olgensis</i>	200	80	700	34.22	-0.0269	0.994	600	3250	4	2	1	3
<i>Abies nephrolepis</i>	250	90	225	30.50	-0.0297	1.062	680	3050	1	2	1	3
<i>Picea koraiensis</i>	300	110	389	30.50	-0.0286	1.052	620	2850	2	4	2	2
<i>Betula platyphylla</i>	100	80	860	28.86	-0.0347	0.920	600	3250	5	2	1	2
<i>Tilia amurensis</i>	300	120	482	28.86	-0.0347	0.920	600	3250	2	3	3	1
<i>Fraxinus mandshurica</i>	250	100	596	24.92	-0.0378	0.937	850	2650	2	4	2	1
<i>Juglans mandshurica</i>	250	80	403	24.92	-0.0378	0.937	850	2650	3	3	2	1
<i>Populus davidiana</i>	80	80	980	26.67	-0.0329	0.913	650	3250	4	2	3	2
<i>Quercus mongolica</i>	400	140	385	26.67	-0.0371	0.978	700	3050	4	1	3	3
<i>Acer mono.</i>	200	70	380	19.11	-0.0483	0.939	700	3050	2	3	2	2
<i>Ulmus japonica</i>	250	90	650	26.67	-0.0329	0.913	700	3050	3	4	2	2

Notes: A_{max} , D_{max} , H_{max} is maximum age, maximum DBH and maximum height of species respectively; G is specific species growth parameter; b_2, b_3 is parameter of Richard function; DD_{min} and DD_{max} are specific species minimum and maximum growing degree days; L, D, M and F : are class of the species shade-tolerance, drought tolerance, wet tolerance and soil fertility intolerance respectively.

Temperature

Temperature effects on tree growth are modeled in terms of growing degree-days. Species response is computed as a parabolic function relating annual degree-days to the minimum and maximum values for a species (Botkin et al. 1972; Shugart 1984; Solomon et al. 1984):

$$f_t(DD) = \frac{4(DD - DD_{min(i)})(DD_{max(i)} - DD)}{(DD_{max(i)} - DD_{min(i)})^2} \quad (5)$$

Where, DD is a growing-season degree-day sum above 5°C

Soil moisture

The effects of soil moisture on tree growth is modeled in ZELIG.CBA in terms of a drought-day index (with the ground-water table is lower than 1 m below the surface in the growth season) and wet index (with the depth of underground water table less than 1 m in the growth season).

In the case of depth of underground water table less than 1 meter in the growth season, the response of trees to the soil moisture is based on simple empirically function such as:

$$f_{sw}(SWI) = [\max(\frac{wt - SWI}{wt}, 0)]^{0.5} \quad (6)$$

Where: wt is species' wet tolerance class, three classes were divided in ZELIG.CBA; SWI is soil wet index which relate to the depth of soil underground water table.

When the depth of underground water more than 1 meter in the growth season, the response of trees to the soil moisture is a function as:

$$f_{sd}(DRI) = [\max(\frac{drt - DRI}{drt}, 0)]^{0.5} \quad (7)$$

Where: drt is species' drought tolerance classes (the main species in Changbai Mountains are divided into five classes based on the characteristic of species); DRI is soil drought day index which was defined as the proportion of days during the growing season for which there is inadequate soil moisture (soil moisture below wilting point, -15 bar). ZELIG.CBA calculate both 20cm depth soil drought day index and 100 cm depth soil drought day index. The 20 cm depth soil drought day index is suitable to modify regeneration and 100 cm depth soil drought day index suitable to modify trees growth.

Soil fertility:

The response of trees to soil fertility is expressed as exponential function such as:

$$f_{sf}(SF) = a_1 \{1 - \exp[a_2(SF - a_3)]\} \quad (8)$$

Where a_1, a_2, a_3 is empirical parameter which depends on the species; SF is relative soil fertility.

Regeneration

There are many micro-environmental factors involved in this process. It is difficult to simulate the mechanism of regeneration. Therefore we would simplified some processes of regeneration. We assume in ZELIG.CBA that the regeneration occurs if two conditions are satisfied. One is viable seed exist and the other is the seeds are dispersed to an area where environmental conditions are suitable for germination and seedling growth. The actual number of

species regeneration every year is equal to the potential maximum number of species regeneration which is modified by soil temperature and soil moisture. We express the process with the function as:

$$N = N_{\max} * f_t * \min\{f_{sd1}, f_{sw1}\} \quad (9)$$

Where f_{sd1} and f_{sw1} are soil moisture modifying factors above 20 cm depth, f_t is temperature factor, N_{\max} is species maximum regeneration number which relate with light in forest and species biological characteristic, ZELIG.CBA use the algorithm of KOPIDE (Shao, 1994).

Mortality

Mortality is modeled as a stochastic event, and may arise from two sources: natural (age-related) mortality and that due to stress from site factors or suppression. The simulation of natural mortality related to aging is based on two assumptions: (1) 1% of individuals survive to reach a species-specific maximum age, and (2) mortality is constant with respect to age. These assumptions provide for suitably long life spans that the annual mortality rate can be approximated as:

$$P_{age} = 4.065 / A_{\max} \quad (10)$$

Where 4.065 is the natural log 0.01 and A_{\max} is maximum age in years.

The stressed individuals are those fail to achieve 10% of their potential growth increment or an absolute diameter increment less than 0.3mm for two or more successive years in ZELIG.CBA. It is assumed that 1% stressed individuals survive to reach 5a for birch and poplar, 15a for *Pinus koraiensis* and 10a for other species. Mortality by stress can be approximated as:

$$P_{stre} = 4.065 / A_{\max} \quad (11)$$

Where A_{stre} is the maximum surviving years of stressed individuals.

Silviculture

The silviculture subroutine consists of a series of regulations and algorithms, such as forest logging (selective cutting and clear cutting), tending and reforestation. Selective cutting algorithm includes selective density regulation of choice cutting species, size and cutting order.

Model validation

Two means are used to test ZELIG.CBA. One is short-term simulation to test reasonability of ZELIG.CBA; the other is long term simulation to test efficiency of ZELIG.CBA.

ZELIG.CBA is fit with the data of 100 permanent plots, which were survived in 1980, 1986 and 1989. The results

(see Tab.2) show the accuracy of the ZELIG.CBA for simulating broad-leaved Korean pine forest growth. The mean error of ZELIG.CBA is less than 5% except for species of *Picea koraiensis*, *Abies nephrolepis*. The maximum error of ZELIG.CBA is less than 10%.

Table 2. The simulation error of ZELIG.CBA

Species	Mean error %	Maximum error %	+/-
<i>Larix olgensis</i>	4.8	8.2	+
<i>Abies nephrolepis</i>	6.1	11.2	-
<i>Picea koraiensis</i>	8.2	12.7	+
<i>Betula platyphylla</i>	2.8	6.5	-
<i>Tilia amurensis</i>	3.5	9.3	-
<i>Fraxinus mandshurica</i>	4.6	10.2	+
<i>Juglans mandshurica</i>	5.0	12.3	-
<i>Populus davidiana</i>	3.6	8.5	+
<i>Quercus mongolica</i>	2.5	7.6	+
<i>Acer mono</i>	3.7	9.2	+
<i>Ulmus japonica</i>	4.2	8.3	-

The long-term simulation test is the simulation of succession from bare ground. The result shows that *Populus davidiana* takes dominance first and then *Betula platyphylla*, the relative important value (RIV) of *Populus davidiana* is 40 and RIV of *Betula platyphylla* is 40 at 30a. The RIV of *Populus davidiana* and *Betula platyphylla*

reach the maximum at 30~40a. The dominance is replaced by *Tilia amurensis* and *Acer mono* after 70-80a. RIV of those species reach climax at about 200a, and then decays after that. The dominant species is replaced by Korean pine (*Pinus koraiensis*) after 300a. *Pinus koraiensis* dominates for a long time. There is no tendency that it is replaced by other species. The RIV ratio of the species is relatively constant. In the broad-leaved Korean pine forest, this result shows the broad-leaved Korean pine forest is in the climax stage.

The simulating result shows the regulation of the broad-leaved Korean pine forest succession. At the beginning of succession from bare ground, the first species invaded into the bare ground is the fast-growing shade-intolerant broadleaf species such as *Populus davidiana* and *Betula platyphylla*. After canopy closure, the relatively shade-tolerant species such as *Tilia amurensis*, *Acer mono* and *Pinus koraiensis* invade. When the shade-tolerant species growing up, the shade-intolerant species died out. Finally, *Pinus Koraiensis* dominate the forest for long time. For the long-term simulation by ZELIG.CBA, simulating result is agreement with regulation of succession of broad-leaved Korean pine forest. Validation for long-term simulation shows that ZELIG.CBA is suitable for long term simulation.

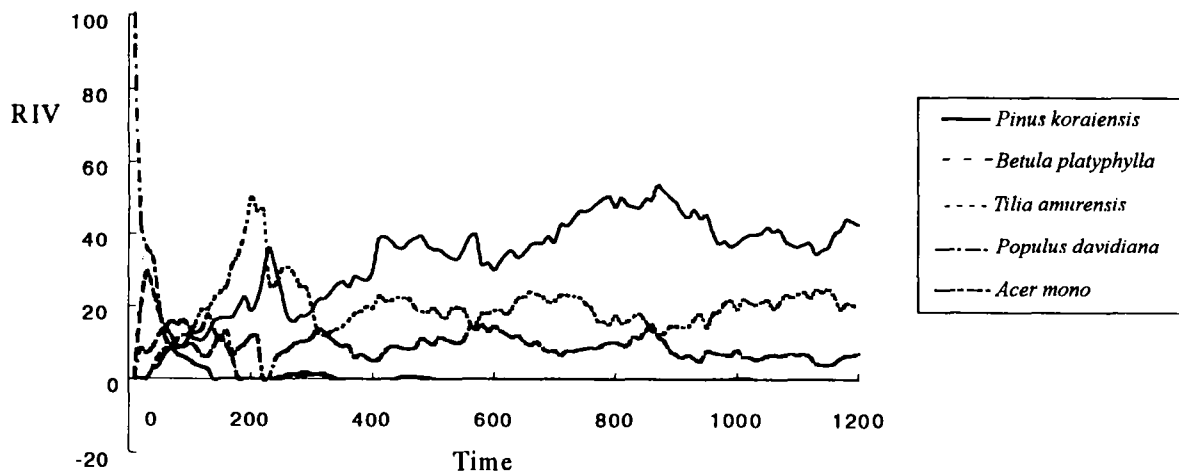


Fig. 1. Forest dynamics after clear cutting

Selective cutting experiment by ZELIG.CBA

In the experiment, 4 scenarios with rotation 30a accompanied with removal 30%, 40% and 50% in wood volume were taken. Another scenario is contrast (undisturbed forest), simulating time is 300a. The results were showed in the Table 3 and Fig. 2

The wood volume of the experimental forest decreases temporarily after cutting and increase up to 250~300

m^3/hm^2 before next cutting when removal is 30% and 40% in volume. There is increasing tendency in volume with removal 30% and 40% but undisturbed there is no increasing tendency with removal 50% in volume. And the remain volume in forest with 50% removal is only $90 \text{ m}^3/\text{hm}^2$. Therefore the scenario of removal 50% in volume is unsuitable for sustainability of broad leaved Korean pine forest and the scenario of removal 30% and 40% in

volume is suitable for sustainability of broad-leaved Kore-

an pine forest. If we just consider wood volume.

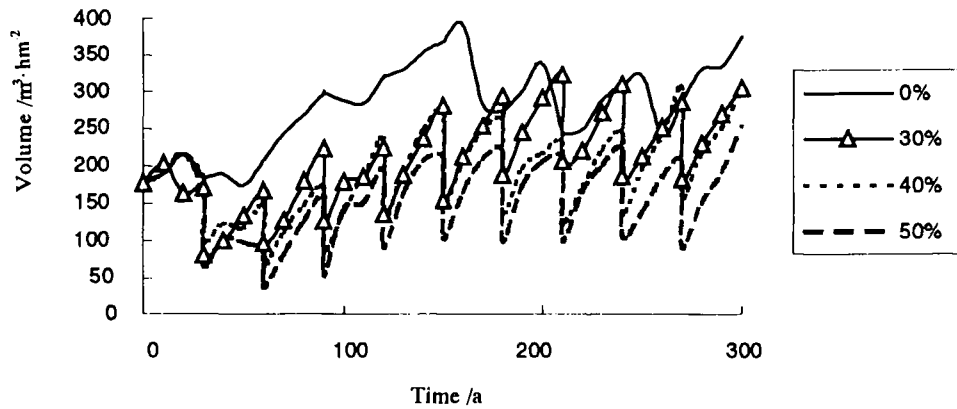


Fig.2 Wood volume dynamics with rotation 30 year

Table 3. The DBH Distribution after Logging in 30a rotation for selecting cutting system

Removal Volume	Time /a	DBH /cm						
		<10	10~20	20~30	30~40	40~50	50~60	>60
30%	30	350.0	116.7	133.3	16.7	0	0	0
	60	2450.0	66.7	33.3	66.7	0	0	0
	90	3166.7	533.3	0.0	16.7	33.3	0	0
	120	2466.7	916.7	0.0	0	16.7	0	0
	150	2683.3	1083.3	83.3	0	0	0	0
	180	2716.7	1066.7	183.3	0	0	0	0
	210	1833.3	1200.0	166.7	16.7	0	0	0
	240	2266.7	883.3	200.0	0	0	0	0
	270	2283.3	1116.7	166.7	16.7	0	0	0
	300	2483.3	1233.3	250.0	50	0	0	0
40%	30	216.7	150.0	100.0	50	0	0	0
	60	2300.0	100.0	66.7	16.7	0	0	0
	90	3883.3	666.7	16.7	0	0	0	0
	120	2933.3	1200.0	0.0	0	0	0	0
	150	1816.7	1133.3	50.0	0	0	0	0
	180	1833.3	1066.7	66.7	0	0	0	0
	210	2316.7	916.7	50.0	0	0	0	0
	240	2800.0	1033.3	66.7	0	0	0	0
	270	2466.7	1466.7	0.0	16.7	0	0	0
	300	2166.7	1733.3	300.0	0	0	0	0
50%	30	166.7	150.0	100	33.3	0	0	0
	60	2066.7	33.3	0	16.7	0	0	0
	90	3566.7	433.3	16.7	0	0	0	0
	120	2566.7	916.7	0	0	0	0	0
	150	2683.3	683.3	33.3	0	0	0	0
	180	2433.3	933.3	33.3	0	0	0	0
	240	2550.0	1633.3	166.7	0	0	0	0
	240	2450.0	866.7	16.7	0	0	0	0
	270	2883.3	866.7	16.7	0	0	0	0
	300	2683.3	1816.7	166.7	16.7	0	0	0

The Table 3 shows the dynamics of DBH distribution in simulated forest and the minimum DBH for the cutting. The minimum DBH for logging is about 30-40 cm and 40~50 cm some about 20~30 cm in the special logging year such as year 150, 180 and year 240 when removal is 30% in volume. The minimum DBH for logging is about 20~30 cm some about 10~20 cm in year 120 and 240 when removal is 40% in volume. The minimum DBH for logging is about 20~30 cm some about 10~20 cm in logging year 120 and 210 when removal is 50% in volume. The optimal logging DBH for *Pinus koraiensis* and *Picea koraiensis* are more than 30cm, and the optimal logging DBH of other deciduous species are 24~28 cm. (Wang and Xu 1980) In summery, the scenario of removal 30% in volume and rotation 30a is sustainable for Korean pine forest.

Conclusions

The validation of the ZELIG.CBA model shows that the accuracy of the model for the forest growth is higher than 95%. For most tree species, the accuracy reaches 90%, that is reasonable for short term simulation. The simulation for succession from clear cutting site shows that the ZELIG.CBA is stable for long term simulation. Therefore ZELIG.CBA is suitable for simulating growth and dynamics of broad-leaved Korean pine forests in Changbai area.

Selective cutting experiment shows the optimal scenario for broad-leaved Korean pine forests is removal volume 30% combining with 30a rotation. But in the actual more than 40% wood volume has been removed combining with 30a rotation in that area. Therefore, for sustainability of Broad-leaved Korean pine forests in Changbai area, it should be reduced logging volume to 30% or the rotation should be extended.

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